Appendix C3. Long-Term Channel Monitoring

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C3.1 BACKGROUND

Green Diamond implemented the initial long-term monitoring program of its California watersheds in 1993. The first two years of the monitoring program was based on two U.S. Forest Service publications which address monitoring strategies of both instream and riparian conditions (Platts et al. 1983; Platts et al. 1987). At the conception of this early monitoring study, the selection of watersheds was primarily influenced by the concerns of the Regional Water Quality Control Board and the CDFG regarding possible cumulative effects of Green Diamond's activities in several basins. The primary watersheds of concern were Salmon Creek and Jacoby Creek, both tributaries to Humboldt Bay. The Salmon Creek watershed was of concern due to its highly unstable and erosive geology (Wildcat Formation) and past management practices. The Jacoby Creek watershed has sections of erosive Franciscan Formations, a diverse mix of ownership and a complex history of watershed disturbances (logging, grazing and residential development). Additional watersheds were selected to distribute the monitoring across the ownership.

The next step in designing the early monitoring program was the selection of sample stream sections within watersheds. Two approaches were utilized in selecting sampling sections:

- Paired reference (control) and test (treatment) sections; and
- A general watershed approach.

When employing the paired reference and test sections, the sections were selected on the basis of their location relative to a potential impact from a management activity (e.g., sedimentation from a timber harvest). Sections established upstream from the activity site were the reference sections and those downstream were the test sections. The data collected from the reference and test sections were compared to evaluate potential impacts. However, to make data comparable, sections above and below the management activity must be selected from stream reaches that matched according to valley bottom and riverine habitat types. Once similar stream reaches were selected, each reach was divided into 300-foot sections from which two 300-foot sections were randomly selected. A minimum of two reference and two test sections were identified for each of Green Diamond's anticipated management activities within a watershed.

Because the location of potential impacts within a watershed cannot always be identified in advance, a general watershed approach must occasionally be utilized. With this approach, the 300-foot stream sections were randomly selected throughout a watershed without identifying them as either reference and test sections. Statistically, a minimum of five to eight sections were sampled, depending on the complexity of the watershed, to insure that suitable reference and test sections would be available following future timber harvest activities. Sampling was conducted following the protocol established by Platts et al. (1983 and 1987).

These pilot projects provided valuable information regarding effective methods and response variables, and the difficulties of analyzing the resulting data. Using the information gathered in these pilot studies, a revised methodology was developed and first implemented in Cañon Creek beginning in 1995.

To fine tune the long-term monitoring methodology, Green Diamond consulted with William Trush, a watershed scientist from Humboldt State University. Trush reviewed the channel monitoring program and suggested modifying the program to reduce data collection time and improve the ability to detect changes in channel response. His review indicated that:

- Most variables measured were flow dependant and generated significant differences in channel conditions with slight changes in base summer flow;
- The systematic selection of monitoring cross sections at ten foot intervals ignored geomorphic characteristics of certain channel features and processes; and
- Flow dependant variables resulted in significant differences regardless of management activities, while systematically selected monitoring cross sections created high variance estimates.

These comments assisted Green Diamond in revising its selection of stream reaches to capture specific channel responses to significant hydrologic events (and possibly management activities) and measuring only variables that were independent of flow. This protocol was implemented on Cañon Creek (a Mad River tributary) in 1995. During 1996, Green Diamond field personnel again monitored the Cañon Creek site and established additional channel monitoring reaches on the South Fork Winchuck River (a tributary in Smith hydrographic unit), Hunter Creek (a lower Klamath River tributary), and Salmon Creek (a Humboldt Bay tributary). These surveys have continued with scheduled re-surveys every two years or after a five year flood event. Data collected on all of the monitoring sites since 1998 are scheduled for analysis in 2003. Each monitoring reach should have at least 3 years of data prior to the first analysis and updated biennially to coincide with the biennial report to the Services (see Section 6 regarding report). The purpose of that monitoring protocol was to document the recovery of Plan Area watersheds from past timber harvesting practices and to evaluate the effects of current and future harvesting practices on watershed condition and recovery. The long-term channel monitoring protocol also has potential to evaluate the effectiveness of “storm-proofing” techniques, currently in vogue, in reducing road-related erosion sources.

C3.2 METHODOLOGY

In early 1998, Green Diamond hired a statistical consultant (Trent McDonald) to assist in refining and developing methods to analyze the long-term channel monitoring data. The consultant confirmed that the data being collected was valid and rendered itself to analysis. Using the previous developed monitoring data collection methods the results were analyzed as described below.

The monitoring objective of the Class I channel monitoring project was to track long term trends in the sediment budget of Class I watercourses as evidenced by changes in channel dimensions. Initially 3 and later 9 monitoring reaches were established in 8 streams across the Plan Area. Two additional reaches were also established with a reduced protocol (thalwag profile only), because the sites did not meet the criteria necessary for doing the full protocol. The initial three streams: Cañon, Hunter, and Canyon creeks were chosen for monitoring and analysis. A section of each creek was selected for monitoring activities and field sampling was carried out on those reaches using Green Diamond's monitoring protocols as described above. Monitored sections were chosen to be the highest (closest to headwaters) depositional reach in each creek. Depositional reaches were characterized by relatively low gradient where sediment was expected to be deposited. The reasoning behind establishment of these monitoring reaches was that if changes in sediment load or other stream morphology parameters occurred anywhere in the watershed, such changes were likely to be reflected in the first depositional reach downstream. The three stream systems under study were small enough that there was only one depositional reach contained in each stream.

Three creeks in the Plan Area (Cañon Creek, Hunter Creek, and Canyon Creek) were chosen for monitoring and analysis. A section of each creek was chosen for monitoring activities and field sampling was carried out on those reaches under Green Diamond protocol. Monitored sections were chosen to be the highest (closest to headwaters) depositional reach in each creek. Depositional reaches were characterized by relatively low gradient where sediment was expected to be deposited. The reasoning behind establishment of these monitoring reaches was that if changes in sediment load or other stream morphology parameters occurred anywhere in the watershed, such changes were likely to be reflected in the first depositional reach downstream. The three stream systems under study were small enough that there was only one depositional reach contained in each stream.

Sampling occurred at Cañon Creek in 1995, 1996, and 1997. Sampling occurred in 1996 and 1997 at the other two creeks (Hunter and Canyon). Each year, thalweg elevation (defined as the height of the deepest part of the channel), bank full width, active channel width, and substrate (pebble) sizes were recorded on the monitoring reaches. Thalweg elevation residuals (see below) were analyzed for changes in variance. A change in thalweg residual variance indicates an improvement (or degradation) of pools via changes in pool depth. Bank full and active channel widths were analyzed for changes in average width. Substrate sizes were analyzed for changes in distribution.

C3.2.1 Analysis of the Thalweg

Thalweg elevation was analyzed for change in mean elevation and thalweg residuals (from a spatial polynomial regression of elevation on distance from the upper end of the reach) were analyzed for change in variance. Both sets of analyses used statistical models appropriate for correlated data. The basic data were pairs of points, (d_i, y_i), where y_i was thalweg elevation and d_i was the distance from the upper terminus of the reach to the point where y_i was measured. Because thalweg elevations were measured relatively close together (approximately every 10 feet) the measurements (i.e., the y_i) were potentially spatially correlated and did not represent independent observations. Therefore, the analyses accounted for this lack of independence by adjusting model coefficients and significance levels using a one dimensional spatial regression model (Cressie 1991; Venables and Ripley 1994). The spatial regression model estimated a one dimensional correlation function among residuals then adjusted estimates and p-values via generalized least squares regression techniques. The spatial regression techniques and the adjustment for auto-correlation is described in more detail in Attachment C3-A.

For the analysis of thalweg elevation, a regression model relating elevation of the thalweg to a cubic polynomial in distance was estimated. Included in this model was a year factor so that the interaction between year and the cubic polynomial in distance could also be estimated. In equation form and provided the reach will be monitored for three years, the regression relationship was:

$$
\begin{aligned}
E[y_i] &= \beta_0 + \beta_1 x_{1,i} + \beta_2 x_{2,i} \\
&+ \beta_3 d_i + \beta_4 d_i^2 + \beta_5 d_i^3 \\
&+ \beta_6 d_i x_{1,i} + \beta_7 d_i^2 x_{1,i} + \beta_8 d_i^3 x_{1,i} \\
&+ \beta_9 d_i x_{2,i} + \beta_{10} d_i^2 x_{2,i} + \beta_{11} d_i^3 x_{2,i}
\end{aligned}
$$

where y_i was thalwag elevation measured at a distance of d_i meters from the top of the reach, $x_{1,i}$ was an indicator variable for year 1 (i.e., 1 if observation $_i$ was taken in year 1, 0 otherwise), and $x_{2,i}$ was an indicator variable for year 2 (i.e., 1 if observation $_i$ was taken in year 2, 0 otherwise). For reaches which were monitored only two years, $x_{2,i}$ and all interactions involving it were eliminated from the model (i.e., β_2, β_9, β_{10}, and β_{11} were not present in the model). These models effectively fit separate cubic polynomials in d_i each year.

The analysis for change in thalweg residual variance was a statistical test designed to detect increased (or decreased) variance in residuals which is indicative of increased (or decreased) pool depths and complexity of the reach habitat. Thalweg residuals were defined as the residuals of thalweg elevation in the above regression model; $r_{yi} = y_{yi} - \hat{y}_{yi}$, where y_{yi} was observed elevation at distance d_i in year y and $\hat{y}_{yi}$ was the predicted elevation at distance d_i in year y. The test for change in thalweg residual variance was carried out using a modified version of Levene's test (Neter et al. 1991). Absolute deviations of the residuals from their median were calculated as $d_{yi} = |r_{yi} - m_y|$, where d_{yi} was the absolute deviation associated with the i-th observation in the y-th year and m_y was the median of residuals in the y-th year. Levene's test entailed carrying out a one-way analysis of variance on the d_{yi}, with year defining the groups. Because the *ryi* were potentially (spatially) correlated, the d_{yi} were also potentially correlated and the one-way analysis of variance was adjusted using the spatial regression techniques outlined in Attachment C3-A. Variance of the original residuals was deemed significantly different across years if the (spatially adjusted) one-way analysis of variance rejected the hypothesis of equal average deviations. The distribution of thalweg residuals was also plotted as a visual interpretation aid.

C3.2.2 Analysis of Width

Both bank full and active channel widths were analyzed for changes across years. To conduct this analysis, a systematic sample of widths was computed from available data after field sampling was complete. Such a systematic sample of widths was necessary because field-sampling protocol dictated that each bank of the creek is measured separately. Consequently, width measurements were not taken completely across the creek, but rather from each bank to a center tape. Furthermore, measurements from one bank to the center tape were not necessarily in the same place as measurements to the opposite bank. Therefore width could not be computed directly from the raw data and consequently a systematic sample of widths was computed and analyzed by the following methods. The systematic sample of widths was computed by first connecting left and right bank width measurements with straight lines to form an approximate stream channel. A random starting point along the center tape was then chosen and widths (across the whole channel) were computed at regular intervals along the center tape. The number of systematic points in the sample was equal to the smaller of the two sample sizes taken on each bank. For example, if 50 measurements were taken on the left bank and 75 measurements were taken on the right bank, 50 systematic measurements of width were taken to analyze. A picture of the systematic sample of widths computed at Cañon Creek in 1996 is presented in Figure C3-1 below.

The systematic sample of widths was computed each year for each creek. Average width was analyzed using one-way analysis of variance (anova) techniques analogous to the modified Levene's test described for analysis of thalweg residual. A one-way analysis of variance (two sample t-test if only two years) was computed, with year as the grouping factor, to test for changes in mean stream width. Because measurements in the field were taken relatively close together and because spacing of the systematic sample of widths was relatively tight, computed widths were potentially correlated and consequently the analysis of variance was modified to adjust for spatial correlations using the techniques outlined in Attachment C3-A. This analysis of variance was parallel to the modified Levene's test described for analysis of thalweg residual variance.

C3.2.3 Analysis of Substrate Size

Substrate size, or pebble size, was measured at between 5 and 10 sites within each monitored reach. Each site was approximately 50 feet by 50 feet in size and consisted of sand bars, lee banks, and other rocky areas in the stream. At each site, field personnel measured the secondary axis of rocks (pebbles) which were collected by selecting one near the toe of their right foot as transects were walked around the site. Collection and measurement continued until 150 rocks were measured. All measurements were reported in millimeters and the smallest measurement was one millimeter.

The distribution of pebble size was plotted and analyzed for changes across years assuming independence of the measurements. Due to the large distances (relative to average pebble size) at which rocks were measured and the fact that several independent systematic samples were taken at each site, spatial correlations among observations were highly unlikely and consequently no adjustments for such correlation were made. The hypothesis of no change in distribution was tested using two sample Wilcoxon rank sum tests (Wilcoxon 1945, Hollander and Wolf 1973) or three sample Kruskal-Wallis tests (Lehmann 1975; Hollander and Wolf 1979), depending on the number of years data were collected from a stream. Substrate size measurements from all sites within a year were combined for testing because site to site differences in substrate size were not of interest and, if such differences existed, would tend to inflate the distribution's variance and provide a conservative analysis. Treating the systematic measurements as if they were purely random (i.e., by assuming independence) also inflates the distribution's variance and further contributes to a conservative analysis.

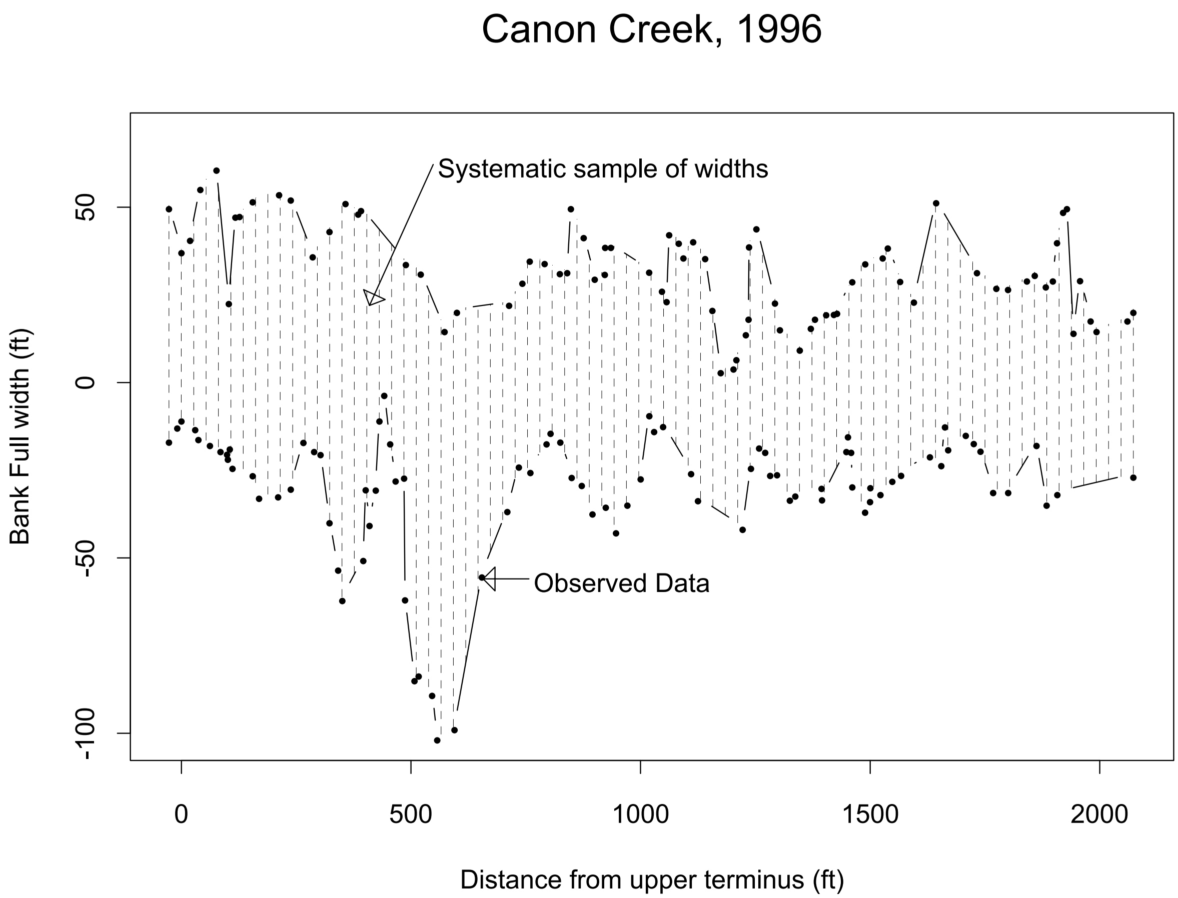

Figure C3-1. **Diagram of the systematic sample of widths taken for the investigation of width (Cañon Creek 1996). This example shows bank full width at Cañon Creek in 1996. Zero in vertical dimension represents the center tape while negative numbers represent the left bank and positive numbers represent the right. Dots are observed bank full measurements with linear interpolation between each. Dashed lines show the systematic sample of widths.**

Three quantiles from each substrate distribution were estimated. The 16-th, 50-th, and 84-th quantiles were estimated from each distribution to facilitate comparison with sediment movement models developed elsewhere (USEPA 2000). The 16-th quantile was defined as that point in the distribution that was greater than 16% of the observations and less than 84% of the observations. By symmetry, the 84-th quantile was defined as that point in the distribution that was greater than 84% of the observations and less than 16% of the observations. The 50-th quantile was defined similarly and corresponded to the median. The standard error of each quantile was estimated using standard bootstrap methods (Manly 1997).

C3.3 RESULTS

C3.3.1 Analysis of the Thalweg

At Cañon Creek, thalweg elevation measurements were significantly correlated with other thalweg elevations measured nearby. Correlation of thalweg residuals (i.e., residuals computed from the initial regression) within 8 feet of one another was 0.52 in 1995 (95% confidence interval 0.21 - 0.83), 0.81 in 1996 (95% confidence interval = 0.46 - 1.0), and 0.73 in 1997 (95% confidence interval = 0.52 - 0.95).

A graph of the final spatial regression model for Cañon Creek appears in Figure C3-2. There was a significant difference in overall curvature of the thalweg profile at Cañon Creek between 1995 and later years ($p<0.0001$ for 1995 vs. 1996; $p<0.0001$ for 1995 vs. 1997). The overall curvature of the thalweg profile was negative in 1995 while in 1996 and 1997 curvature was positive. Inspection of Figure C3-2 shows that the middle half (approximately) of the Cañon Creek monitoring reach remained at roughly the same elevation in all three years, but that the upper and lower quarters (approximately) were lower in 1995 and than in 1996 and 1997. No significant differences existed in the linear or cubic trends between 1995, 1996, and 1997. No significant differences existed in overall thalweg trend between 1996 and 1997 ($p=0.29$ for linear trend, $p=0.37$ for quadratic trend, $p=0.77$ for cubic trend).

Thalweg elevation measurements in Hunter Creek were significantly correlated with similar measurements taken nearby. Correlation of thalweg residuals within 8 feet of one another was 0.44 in 1996 (95% confidence interval 0.11 - 0.78), and 0.98 in 1997 (95% confidence interval 0.64 - 1.0).

A graph of the final spatial regression model for Hunter Creek appears in Figure C3-3. A marginally significant difference existed in the coefficient of the cubic trend term between 1996 and 1997 at Hunter Creek ($p=0.072$). This difference in third order trend, if deemed significant, was caused by a drop in thalweg elevation from 1996 to 1997 near the bottom third of the monitoring reach, between 1500 and 2200 feet from the upper terminus of the reach.

Thalweg elevation measurements in Canyon Creek were significantly correlated with similar measurements taken nearby. Correlation of thalweg residuals in Canyon Creek within 8 feet of one another was 0.69 in 1996 (95% confidence interval = 0.42 - 0.97), and 0.65 in 1997 (95% confidence interval = 0.43 - 0.87).

A graph of the final spatial regression model for Canyon Creek appears in Figure C3-4. No significant differences occurred in overall thalweg elevation in Canyon Creek between 1996 and 1997 (p= 0.36 for year*linear term, p=0.78 for year*quadratic term, p=0.10 for year*cubic term). Because yearly interaction was not significant, interaction was dropped from the final regression at Canyon Creek and consequently the lines in Figure C3-4 were forced to be exactly parallel. There was no difference in the parallel lines of Figure C3-4 (p=0.67).

The distributions of thalweg residual for Cañon, Hunter, and Canyon creeks appear in Figure C3-5, Figure C3-6 and Figure C3-7. In addition to standard histograms, these figures display a (Gaussian) kernel smooth density estimate for each distribution. Absolute deviations from the median, used in Levene's test, measured near one another were significantly correlated in every creek every year.

Table C3-1 contains estimates and confidence intervals for correlation between absolute deviations within 8 feet of one another. After adjustment for spatial correlation using the method outlined in Attachment C3-A, there remained a significant decrease in thalweg residual variance at Cañon creek between 1995 and latter years (p=0.0019 for 1995 vs. 1996; p=0.0013 for 1995 vs 1997).

Inspection of the histograms in Figure C3-5 confirm that there were more large negative thalweg residuals in 1995 than there were in 1996 and 1997. There was no significant difference in thalweg residual variance between 1996 and 1997 at Cañon Creek (p=0.5379). Thalweg residuals at Hunter and Canyon creeks displayed changes similar to those at Cañon Creek. Variance of thalweg residuals was higher in 1996 than 1997 at both Hunter and Canyon creeks (p=0.0465 for Hunter, p=0.0365 for Canyon). Inspection of Figure C3-6 and Figure C3-7 confirm that there were more large negative residuals in 1996 than in 1997 at both creeks.

Table C3-1. Estimated correlations among absolute thalweg residual deviations from the median measured less than 8 feet apart.

Creek	Year	Estimated Correlation	Approximate 95% confidence interval	
			Low	High
Cañon	1995	0.50	0.19	0.81
	1996	0.83	0.49	1.00
	1997	0.70	0.49	0.91
Hunter	1996	0.38	0.05	0.72
	1997	0.89	0.55	1.0
Canyon	1996	0.70	0.42	0.97
	1997	0.60	0.38	0.82

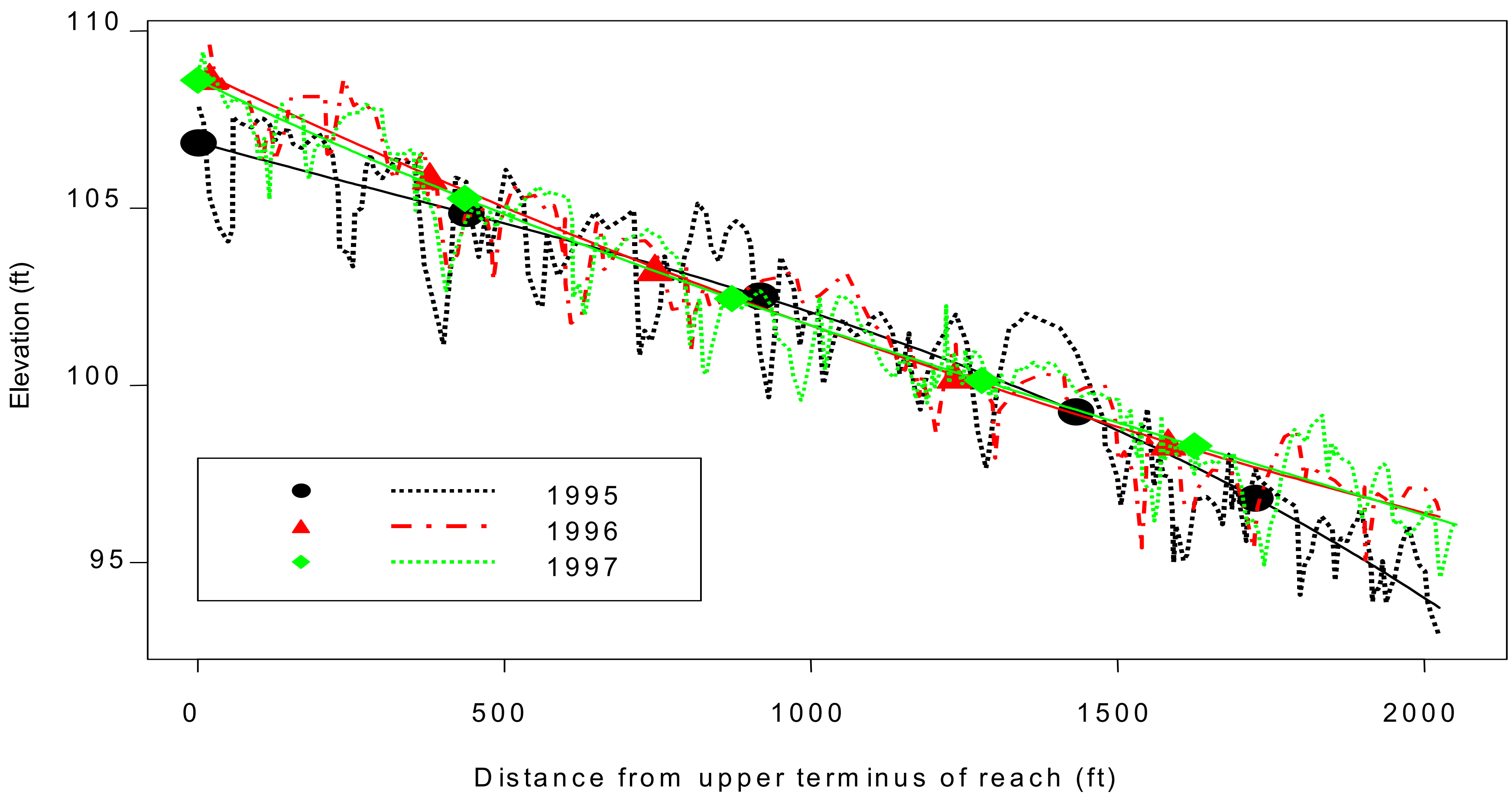

Figure C3-2. **Thalweg elevation profile for the Cañon Creek monitoring reach, 1995, 1996, and 1997. Dashed lines show measured elevations. Solid lines show trend estimated by spatial regression that adjusted for auto-correlation in residuals. Curvature (2nd derivative) was negative in 1995, positive in 1996 and 1997.**

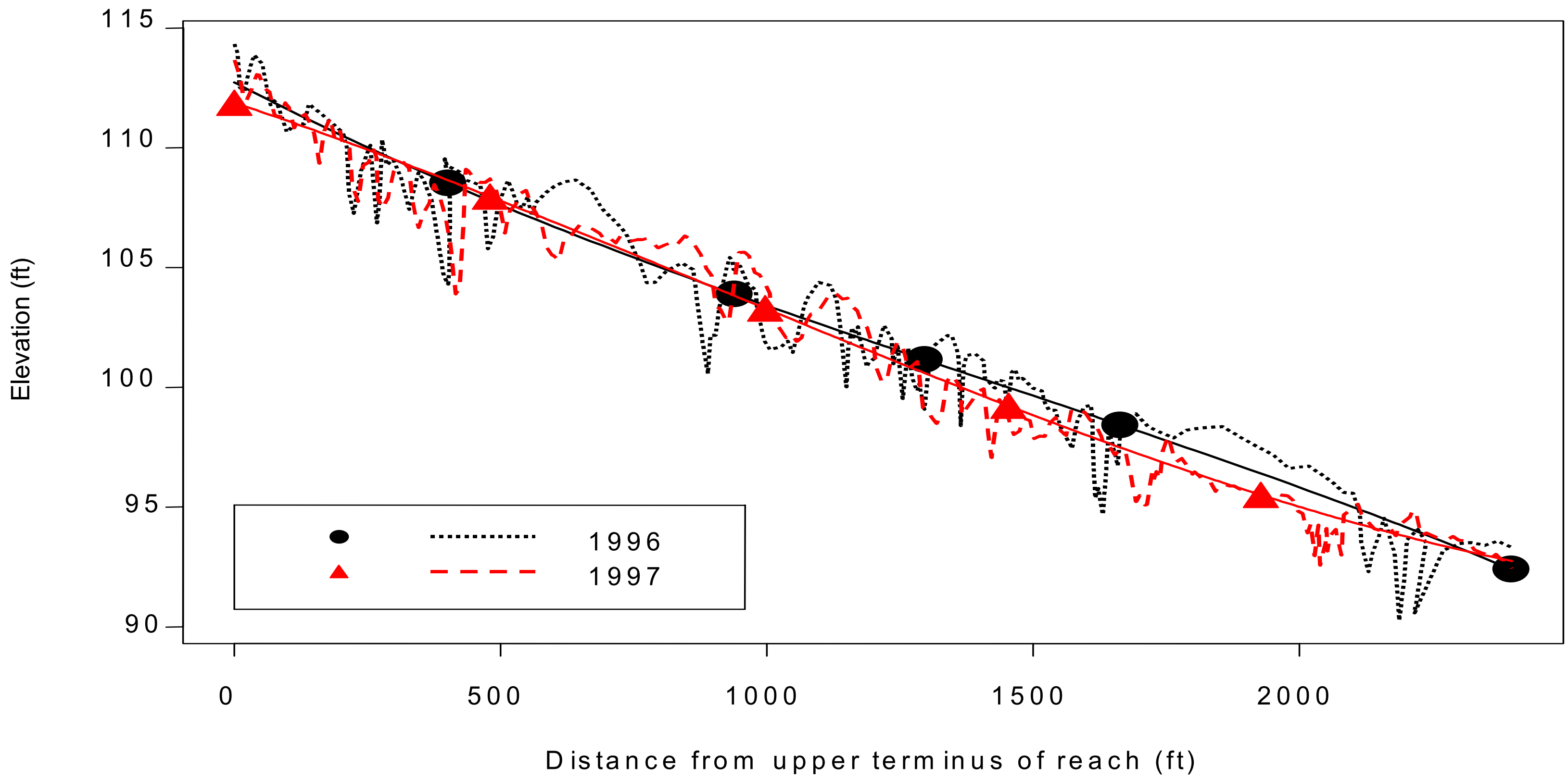

Figure C3-3. **Thalweg elevation profile for the Hunter Creek monitoring reach in 1996 and 1997. Dashed lines show measured elevations. Solid lines show trend estimated by spatial regression that adjusted for auto-correlation in residuals.**

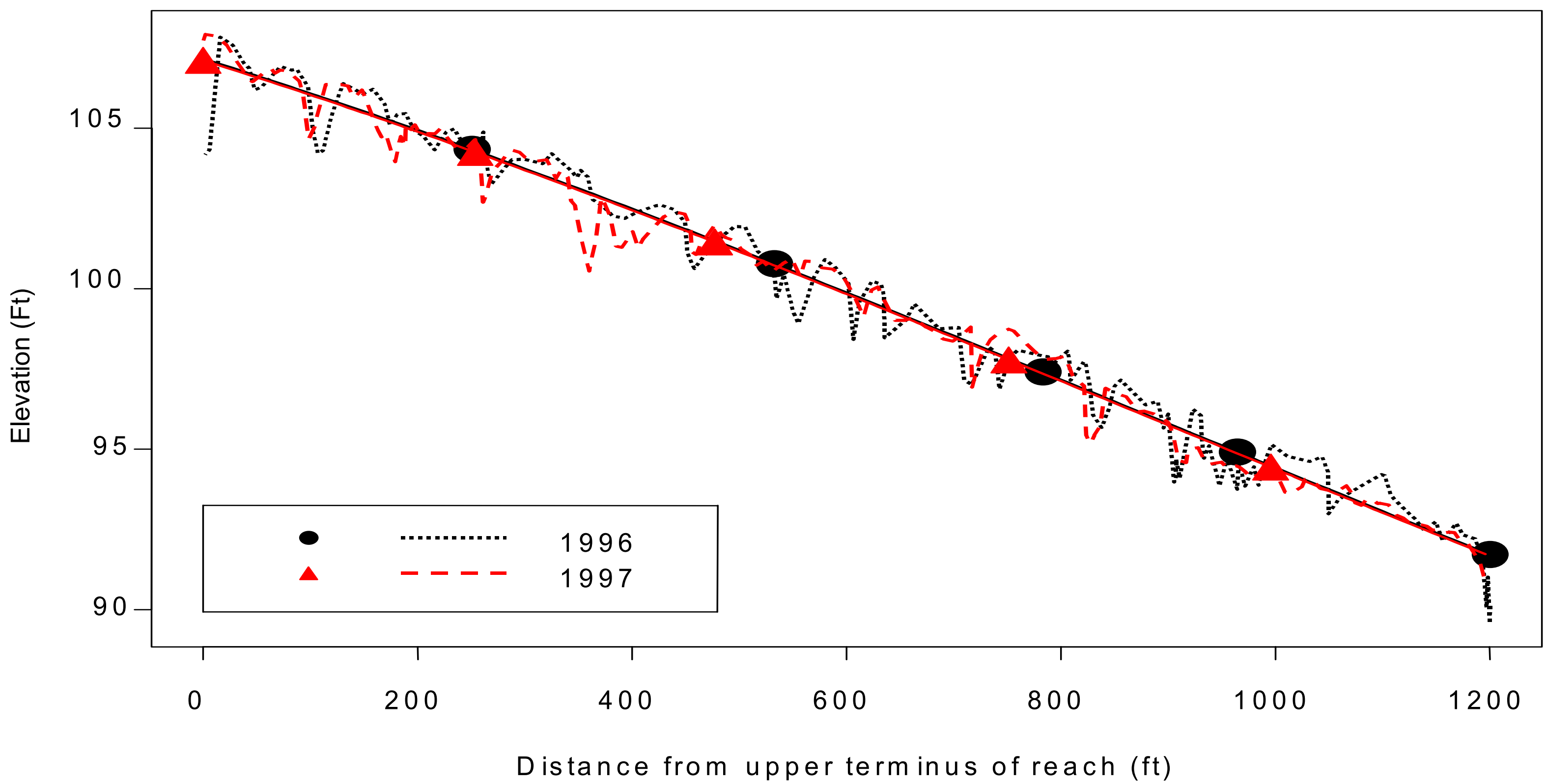

Figure C3-4. Thalweg elevation profile for the Canyon Creek monitoring reach in 1996 and 1997. Dashed lines show measured elevations. Solid lines show trend estimated by spatial regression that adjusted for auto-correlation in residuals.

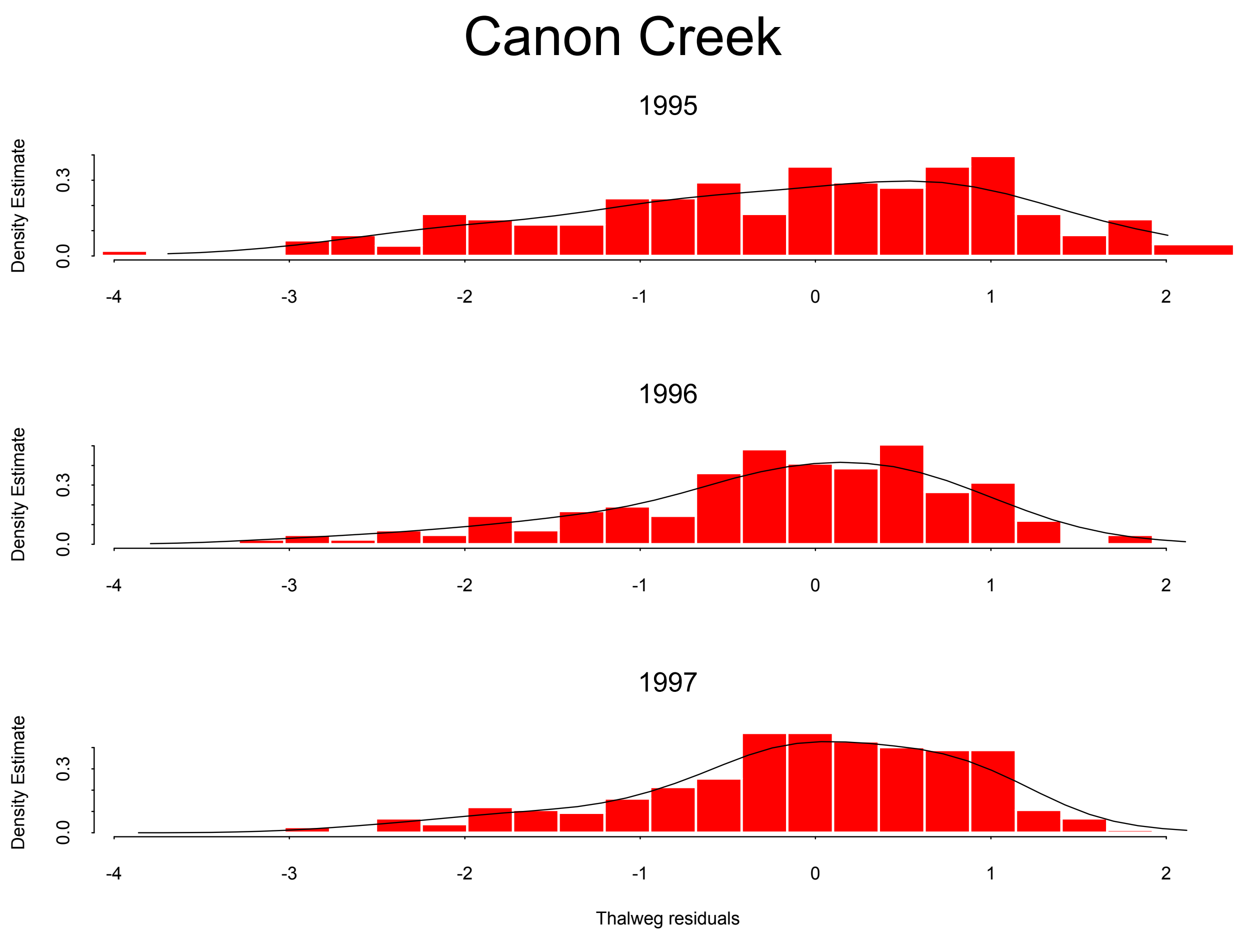

Figure C3-5. **Histograms of thalweg residuals at Cañon Creek, 1995 through 1997, used to compare variance of residuals among years. Residuals computed using models fit in Figure C3-1. Solid line is Gaussian kernel smoothed density estimate.**

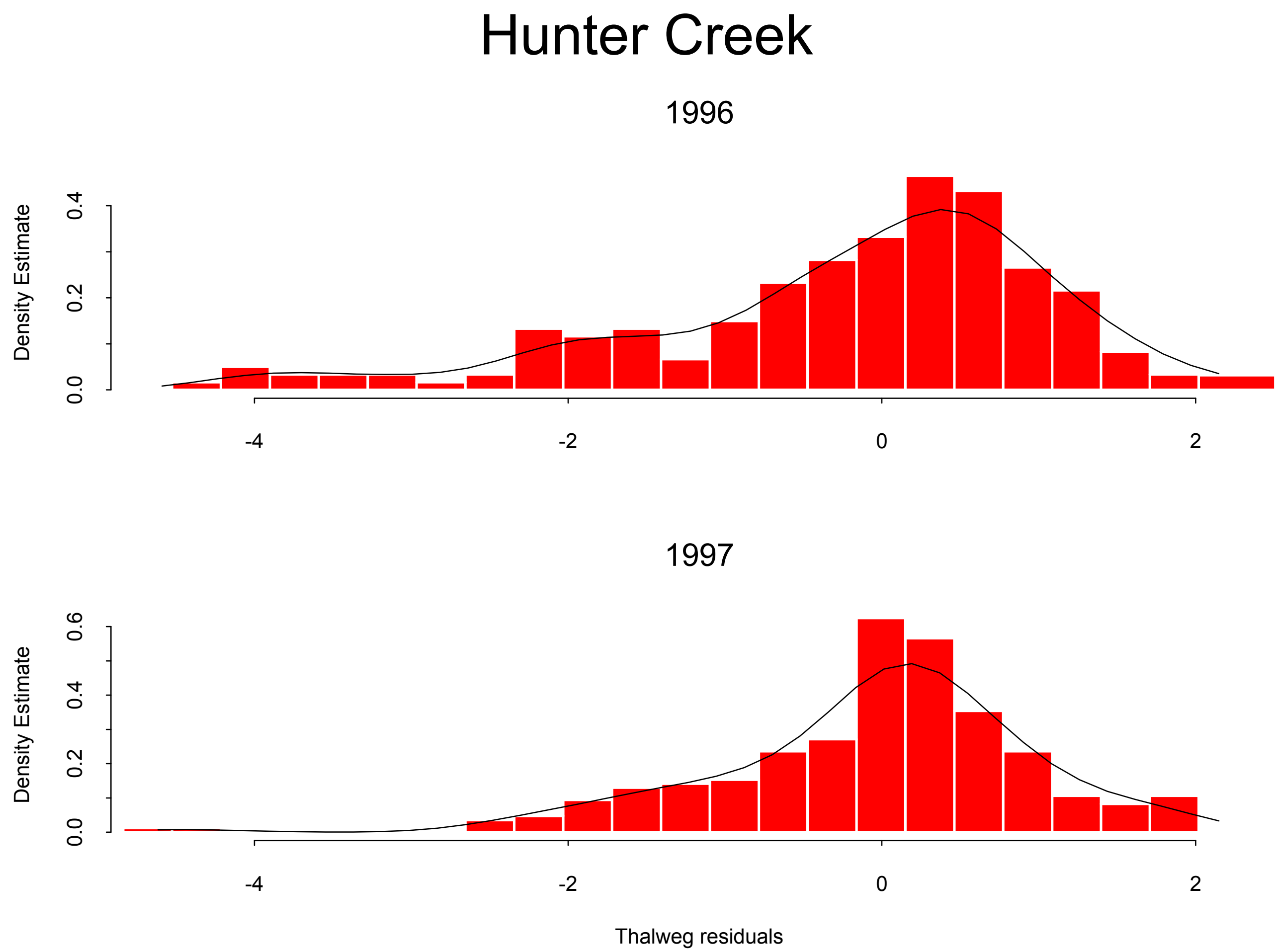

Figure C3-6. **Histograms of thalweg residuals at Hunter Creek, 1996 and 1997, used to compare variance of residuals among years. Residuals computed using models fit in Figure C3-2. Solid line is Gaussian kernel smoothed density estimate.**

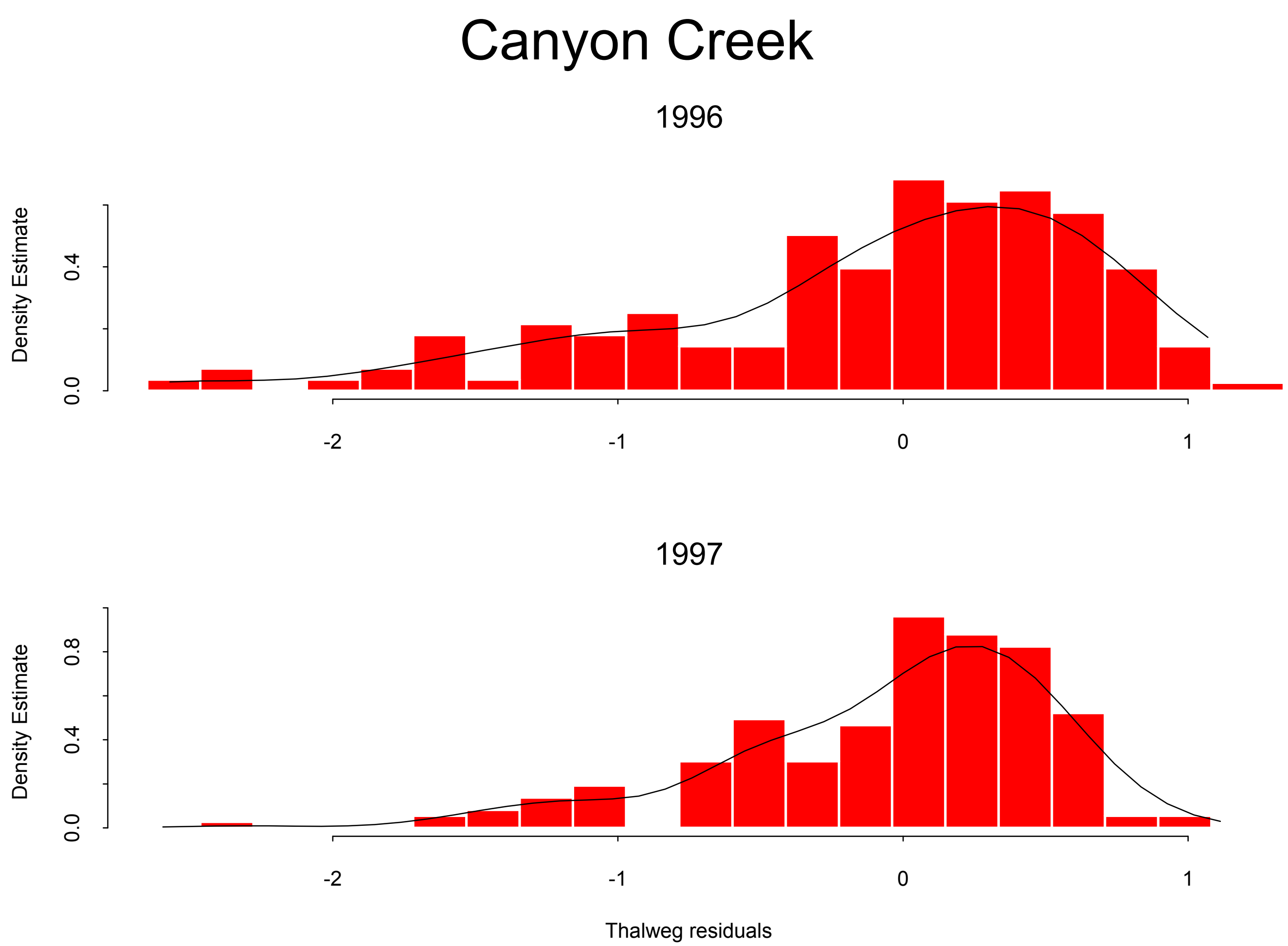

Figure C3-7. **Histograms of thalweg residuals at Canyon Creek, 1996 and 1997, used to compare variance of residuals among years. Residuals computed using models fit in Figure C3-3. Solid line is Gaussian kernel smoothed density estimate.**

C3.3.2 Analysis of Width

Both bankfull and active channel width measurements were significantly correlated when measured close together. For bank full width at Cañon Creek, the estimated correlation among measurements within 100 feet of one another was generally greater than 0.5 in all years and never lower than 0.32. The estimated correlation among active channel width measurements at Cañon Creek which were within 100 feet of one another was greater than 0.47 in all years and as high as 0.82 for measurements within 25 feet of one another. Similar high spatial correlations were observed in Hunter and Canyon creeks. Correlation of both bankfull and active channel widths measured within 50 to 75 feet of one another was generally greater than 0.5. Consequently, substantial adjustments were made to the estimates and p-values when correlations were accounted for.

Table C3-2 contains estimated mean bankfull and active channel widths for all years of the study. Values reported in Table C3-2 were obtained from the coefficients of the spatial regression (anova) model and standard errors are adjusted for estimated correlations. At Cañon Creek, the observed increase in mean bank full width from 1995 to 1996 was almost statistically significant at the α=0.05 level (p=0.054). Mean bank full width at Cañon Creek was significantly bigger in 1997 when compared to 1995 (p=0.015), but there was no difference in bankfull width between 1996 and 1997 (p=0.57). Active channel widths followed a pattern similar to bankfull. Active channel width at Cañon Creek increased significantly between 1995 and subsequent years (p<0.0001 for 1995 vs. 1996; p<0.0001 for 1995 vs. 1997), but remained constant between 1996 and 1997 (p=0.45 for 1996 vs. 1997). At Hunter Creek, neither bank full and active channel width changed significantly between 1996 and 1997 (p=0.90 for bankfull, p=0.88 for active channel). At Canyon Creek, the change in bankfull width between 1996 and 1997 was almost statistically significant at the α=0.05 level (p=0.057). Active channel width at Canyon Creek was not significantly different between 1996 and 1997 (p=0.25).

Table C3-2. Estimated bankfull and active channel width for all years of the study.[1]

Creek	Year	Estimated Mean Bankfull Width (ft)	Standard Error, Bankfull	Estimated Mean Active Channel Width (ft)	Standard Error, Active Channel
Cañon	1995	47.39	4.68	29.51	2.64
	1996	62.06	5.97	47.16	2.36
	1997	67.15	6.61	50.78	4.11
Hunter	1996	56.2	3.42	38.5	3.15
	1997	57.0	5.13	37.8	3.40
Canyon	1996	33.4	1.39	20.8	1.04
	1997	27.0	3.00	18.6	1.58

Note
1 Estimates and standard errors were computed from the spatial regression model that accounted for spatial correlation. All measurements in feet. Significance levels can be found in the text.

C3.3.3 Analysis of Substrate Size

Figure C3-8, Figure C3-9, and Figure C3-10 display estimates of substrate size distribution for the three monitored creeks for all years of the study. Table C3-3 contains the estimated 16-th, 50-th, and 84-th quantiles from each distribution depicted in the figures, as well as each quantile's bootstrap standard error.

Table C3- 3. Estimated quantiles of substrate distributions found in three monitored creeks.[1]

Creek	Year	16th Quantile (Standard Err.)	50th Quantile (Standard Err.)	84th Quantile (Standard Err.)
Cañon	1995	14 (0.59)	36 (0.94)	68 (1.62)
	1996	11 (0.60)	29 (0.91)	63 (1.77)
	1997	16 (1.59)	44.5 (1.91)	80 (2.29)
Hunter	1996	17 (0.85)	41 (1.69)	85 (2.60)
	1997	15 (0.76)	44 (1.55)	98 (3.36)
Canyon	1996	9 (0.73)	35 (1.22)	67 (1.58)
	1997	15 (1.25)	43.5 (1.53)	84 (2.45)

Note
1 Standard errors of each quantile computed using 1000 bootstrap iterations. All measurements in millimeters (mm). 50-th quantile is the median.

The three distributions of pebble size at Cañon Creek, depicted in Figure C3-8, were all significantly different from one another ($p<0.0001$, Kruskal-Wallis; $p<0.0001$ Wilcoxon 1995 vs. 1996; $p<0.0001$, Wilcoxon, 1995 vs. 1997; and $p<0.0001$, Wilcoxon, 1996 vs. 1997). Although marginally difficult to visualize in Figure C3-8, the tests and values in Table C3-3 indicated that, in general, the distribution of pebble size shifted to the left (smaller) from 1995 to 1996 and then shifted back to the right (larger) from 1996 to 1997. Most of the distributional differences among years at Cañon Creek can be attributed to differences in the right hand tail of the distribution, with relatively more small substrate observed in 1996.

The distribution of pebble size at Hunter Creek was marginally significantly different between 1996 and 1997 ($p=0.061$, Wilcoxon). Quantiles reported in Table C3-3 indicated that the change in distribution, although not significant at the $\alpha=0.05$ level, involved a slight increase in the relative frequency of larger pebbles in 1997, relative to 1996.

The distribution of pebble size at Canyon Creek increased from 1996 to 1997 ($p<0.0001$, Wilcoxon). Inspection of Table C3-3 and Figure C3-10 reveals that almost all of the distribution of pebble size shifted to the right (larger) in 1997 at Canyon Creek, relative to 1996.

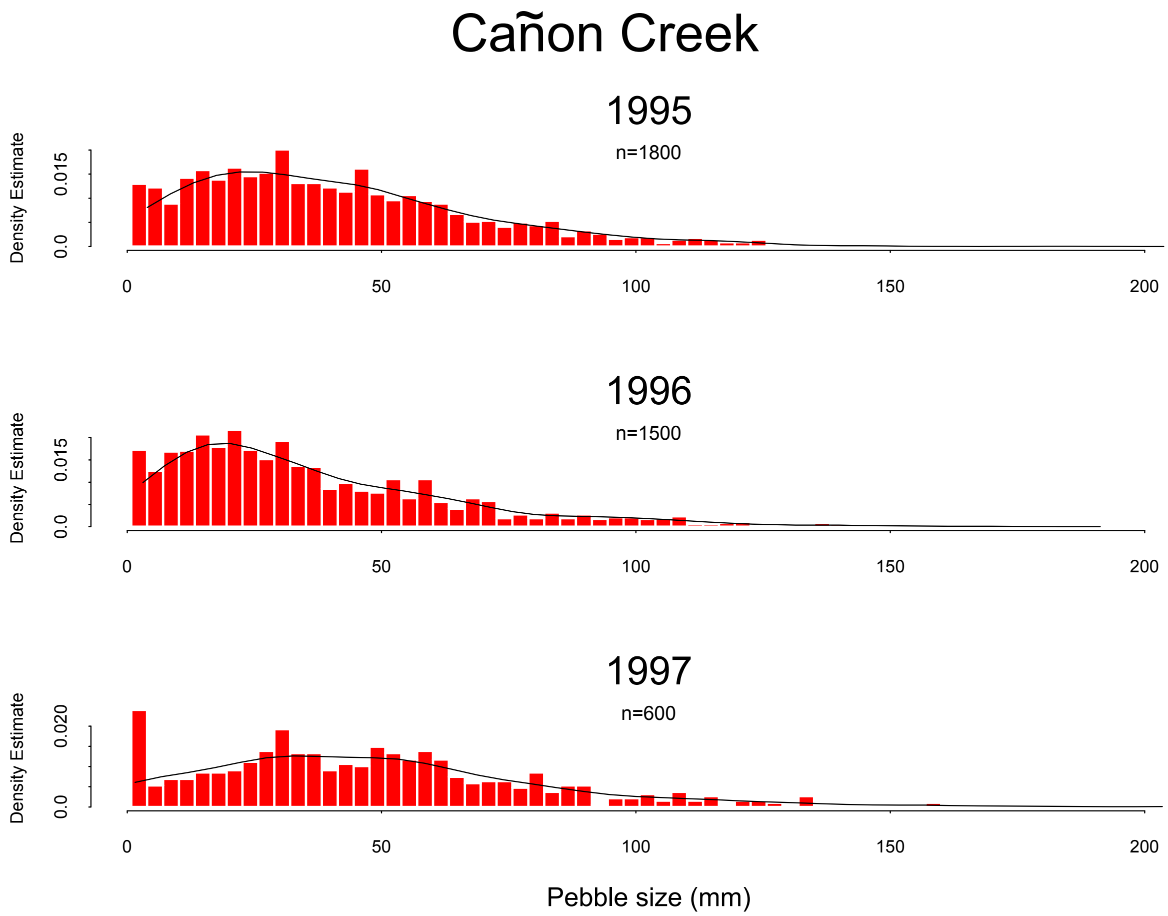

Figure C3-8. Estimated distributions of pebble size in Cañon Creek during the study. Solid lines are Gaussian kernel smooth density estimates.

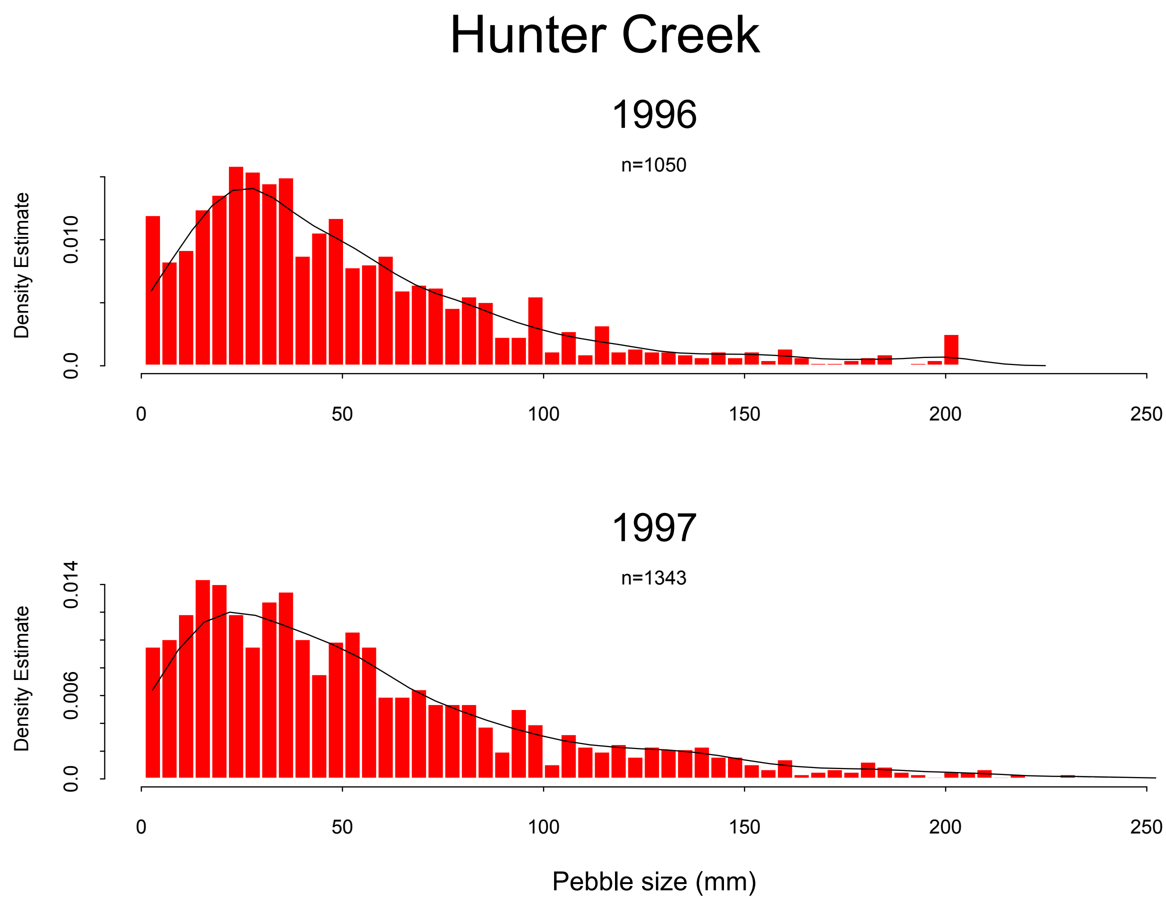

Figure C3-9. **Estimated distributions of pebble size in Hunter Creek during the study. Solid lines are Gaussian kernel smooth density estimates.**

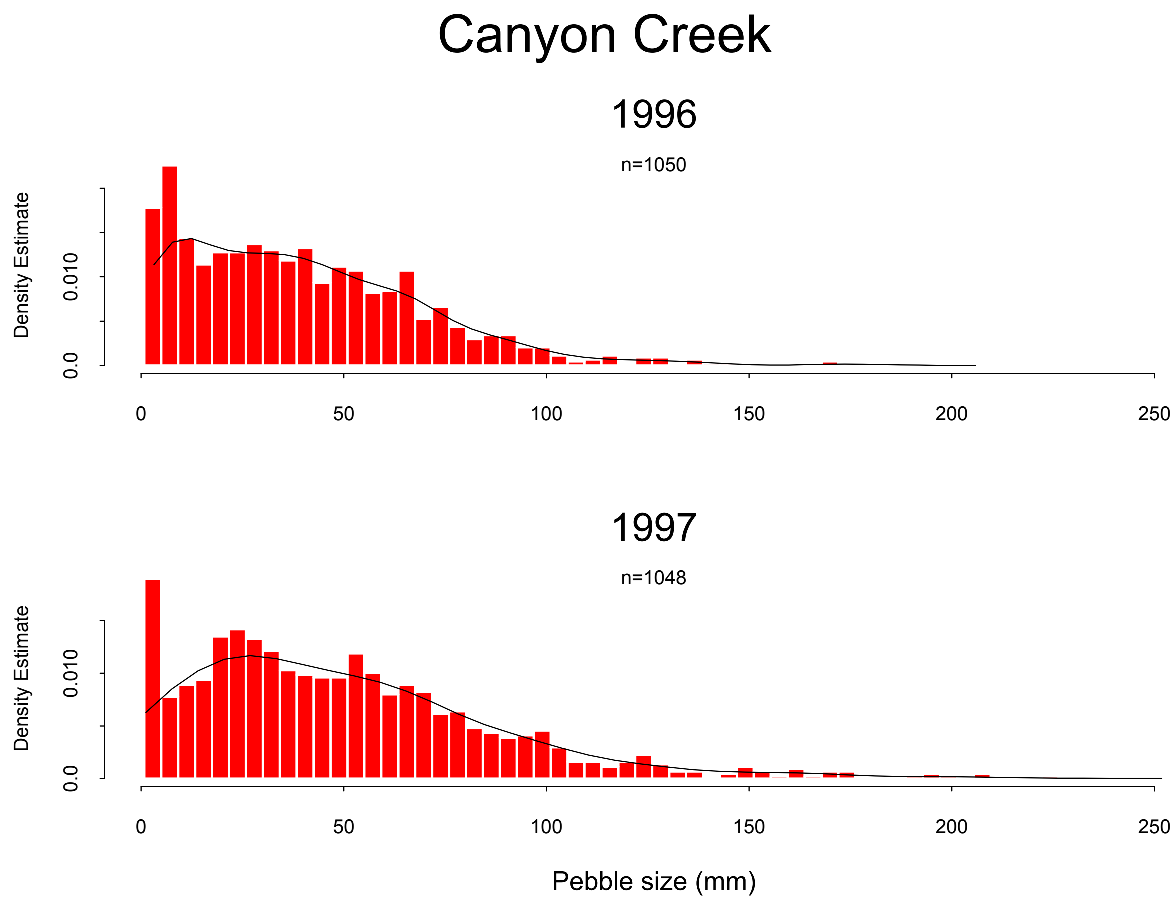

Figure C3-10. Estimated distributions of pebble size in Canyon Creek during the study. Solid lines are Gaussian kernel smooth density estimates.

As a caution when interpreting the results of this section, note that the number of pebbles measured in each creek each year was quite high (number of pebbles measured is given as >n= in Figure C3-8 through Figure C3-10). Such large sample sizes caused high statistical power to detect even relatively small differences in distributions. Small differences, although statistically significant, should be judged as to whether or not they are of any practical importance before any management decisions are made.

C3.4 DISCUSSION

The fundamental assumption associated with the long term channel monitoring is that the morphology of a depositional stream reach acts as a response surface for upslope sediment inputs. When sediment delivery increase beyond the capacity of the stream to transport it, depositional reaches will become aggraded, reduced sediment inputs will result in the opposite response. Although the morphological changes of stream reaches due to upslope sediment inputs have been well documented (Swanston 1991; Benda 1990; Benda and Dunne 1987; Hagans et al. 1986; Heede 1980), there are limitations associated with using this phenomenon for monitoring hillslope sediment production.

Quantification of some of the complex changes in channel morphology that result from changes in sediment supply can be problematic. Some changes such as the degree of sinuousity of a given stream reach generally follow predictable patterns depending on changes in the sediment load, but quantification in a statistically rigorous manner may not be possible. To deal with this potential problem, the channel monitoring protocol has been refined over time to focus on variables that respond in predictable ways and lend themselves to statistical analysis. The primary response variables that were determined to be suitable for measurement with minimum subjectivity and rigorous statistical analysis include changes in thalweg elevation and residuals, bankfull and active channel width, and substrate particle size distribution.

One of the most commonly raised concerns related to using channel morphology for monitoring is the lag times that can be associated with upslope sediment inputs and the corresponding response in the depositional reach. There is also a potential problem associated with separating natural sediment inputs from management related inputs. Both of these limitations are exacerbated with increasing distances between the upslope sediment sources and the depositional reach. As a result, the use of this monitoring approach was limited to depositional stream reaches that are closely coupled to transport reaches and potential hillslope sediment sources. Ideally, each monitoring reach is located in the watershed such that it is the first depositional reach immediately below continuously confined high gradient reaches that deliver sediment from upslope delivery sites with no capacity to store sediments in route. In reality, it is usually not possible to find the ideal monitoring reach and the selected reaches vary in how closely they are located to transport reaches and the extent to which sediments can be stored upstream of the monitoring site.

However, the response variables were found to be sensitive to mass wasting and major storm events, which have been shown to significantly change the channel dimensions. For example in Canon Creek, there was a significant decrease in the thalweg residual variance between 1995 and 1996. Between these two sampling years, there was a 10-15 year flood event (January 1996) that altered the channel morphology. The resurvey during the summer following the January 1996 flood indicated that the frequency of large deep pools decreased and the upstream and downstream ends of the monitoring reach aggraded. In this particular case, the response time was rapid in terms of showing changes in the morphology of the reach following a storm. However, Canon Creek has several miles of upstream transitional reaches that have the capacity of storing sediment, so that the aggrading of the channel did not necessarily indicate increased hillslope sediment inputs during the 1996 flood. This short coming of some of the first monitoring reaches has been recognized, and subsequent monitoring reaches have been placed so that this problem will be minimized. Although the data have not yet been analyzed, there is strong evidence that a second Hunter Creek monitoring reach located further upstream responded dramatically to a mass wasting event triggered higher up in the watershed during a November 1998 storm. The changes in the monitoring reach appeared to occur within days of the storm event. Given the differences in their placement, Green Diamond believes that the current monitoring sites have a range of response times that can vary from days to 1-2 years following a >5-year storm event. The individual response time of each monitoring site will be confirmed over time through additional monitoring.

An additional challenge associated with using channel dynamics for monitoring purposes is understanding the range of natural variability that is associated with any given stream. As a result, it likely will be necessary to continue monitoring for extended periods of time to develop a full understanding of the natural relationship between storm recurrence intervals and stream morphology. Even though it may be difficult to delineate natural variability from anthropogenic changes in the near term, Green Diamond believes that many useful insights will be gained in understanding the link between hillslope processes and channel morphology.

C3.5 CONCLUSION

This is a long term monitoring study, and therefore Green Diamond does not expect to be able to determine trends in the sediment budget of Class I watercourses for possibly 10-15 years. Threshold values for monitoring can not be established until lag times and the range of natural variability for individual watersheds or sub-basins are understood. In the interim period, Green Diamond expects to gain useful insights concerning the relationship between channel dynamics and hillslope processes within the Plan Area. By integrating data from different monitoring approaches, Green Diamond believes that channel monitoring will ultimately be a powerful tool for better understanding of the relationship between management activities and stream habitat condition for the Covered Species in the Plan Area.

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ATTACHMENT C3-A

This attachment describes the spatial regression technique used in the analysis of mean thalweg elevation, thalweg residuals, and mean channel width. This spatial regression analysis attempted to account for spatial correlations in the responses, which arise because measurements were taken close together. The technique can be described in three steps; 1) ordinary least squares parameter estimation, 2) auto-correlation modeling, and 3) weighted linear regression. Each step is described below.

Step one of the spatial regression analysis estimated a regular (Normal theory) regression of responses (i.e., thalweg elevation, thalweg residual, or channel width) onto a set of indicator variables and/or other explanatory study covariates. For example, the analysis for change in average thalweg elevation related elevation of the thalweg to a cubic polynomial of distance. The models for thalweg residual and channel width were analysis of variance (anova) models and contained indicator functions delineating the years of the study. More details about the models used for each response can be found in the main body of this report.

Step two of the spatial regression analysis estimated and modeled the auto-correlation among observed regression residuals. Estimated auto-correlations among residuals were deemed significant at various distances if an approximate 95% confidence interval surrounding Moran's *I* statistic (Moran 1950) did not contain zero. Moran's *I* was computed for relatively short lag distances, longer lag distances were ignored. If significant auto-correlation were found in the residuals, a non-linear correlation model which predicted correlation as a function of the distance between measurements was fit to the estimated correlations (see below for the form of the variance model). Auto-correlations (if significant) were modeled (spatially) within year and no (temporal) correlation was allowed across years.

If significant auto-correlations existed, a *spherical* variance model (Cressie 1991) was fit to model correlations as a function of distance. The spherical variance model had the form $v(d_{ij}) = c_1(1-1.5(d_{ij}/h_0)-0.5(d_{ij}/h_0)^3)$ if d_{ij} #h_0 and 0 if $d_{ij} > h_0$ where d_{ij} was the distance between measurements $_i$ and $_j$, and c_1 and h_0 were parameters to be estimated (c_1 is commonly called the intercept and h_0 is commonly called the range). The parameters c_1 and h_0 were estimated by forming all possible statistics $z_{ij} = (r_i - \mu\ r)(r_j - \mu r)/s_r^2$, where r_i was the regression residual from the $_i$-th observation and s_r^2 was the sample variance of the residuals, and plotting the z_{ij} against d_{ij}. This graph was then smoothed using a Gaussian kernel smoother (Venables and Ripley 1994; Statistical Sciences 1995) and the spherical model was fit to the smoothed estimates using non-linear least squares estimation techniques (Statistical Sciences 1994, documentation for nlminb function). Kernel smoothing was carried out by the S-Plus function ksmooth (Statistical Sciences, 1995).

Step three of the spatial regression analysis used the estimated variance-covariance matrix derived from the variance model computed in step two as a weight matrix to re-compute coefficients, standard errors, and p-values obtained at step one. This weighted regression step is described next. Assume X was the original design matrix used in the regression model at step one which contained indicator variables and/or polynomials in distance. Assume Y was the vector of responses, and V was the estimated variance-covariance matrix obtained at step two. The re-computed vector of coefficients, $\hat{\beta}$, and variance was,

$$\hat{\beta} = (X'V^{-1}X)^{-1}X'V^{-1}Y$$
$$\text{var}(\hat{\beta}) = (X'V^{-1}X)^{-1}.$$

Significance of an element in $\hat{\beta}$ was assessed by comparing the ratio of the element to its standard error to a (Student's) T distribution having *n*-*p* degrees of freedom (*n* was total number of observations, *p* was the number of columns in X). This test is commonly referred to as a Wald t-test (Venables and Ripley 1994).